POWER QUALITY IMPROVEMENT BY HARMONIC REDUCTION USING THREE PHASE SHUNT ACTIVE POWER FILTER WITH p-q & d-q CURRENT CONTROL STRATEGY

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A thesis submitted in partial fulfilment of the requirements for the degree of

Bachelor of Technology in "Electrical Engineering"

BY

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CERTIFICATE

This to certify that the thesis report entitled "**POWER QUALITY IMPROVEMENT BY HARMONIC REDUCTION USING THREE PHASE SHUNT ACTIVE POWER FILTER WITH p-q & d-q CURRENT CONTROL STRATEGY**" is a bona fide work carried by **DIBYENDU BHADRA**, **ROLL NO: 111EE0429**, in partial fulfillment for the award of Bachelor of Technology in Electrical Engineering at **National Institute of Technology**, **Rourkela** during the year 2014-2015 under my supervision and guidance. The thesis report has been approved as it satisfies the academic requirements in respect of Project work prescribed for the said Degree. The thesis report which is based on candidate's own work has not been submitted elsewhere for a degree/diploma.

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ABBREVIATIONS AND ACRONYMS

SCR – Silicon Controlled Rectifier

IGBT – Insulated Gate Bipolar Transistor

MOSFET – Metal Oxide Semiconductor Field Effect Transistor

APF – Active Power Filter

PCC – Point of Common Coupling

SMPS – Switched Mode Power Supply

UPS – Uninterruptible Power Supply

AC – Alternating Current

DC – Direct Current

THD – Total Harmonic Distortion

PWM – Pulse Width Modulation

VSI – Voltage Source Inverter

SAPF – Shunt Active Power Filter

FFT – Fast Fourier Transform

DSP – Digital Signal Processing

PLL – Phase Locked Loop

LPF – Low Pass Filter

ADC – Analog to Digital Converter

IC – Integrated Circuit

ABSTRACT

With the widespread use of power electronics devices such as rectifier, inverter etc. in power system causes serious problem relating to power quality. One of such problem is generation of current and voltage harmonics causing distortion of load waveform, voltage fluctuation, voltage dip, heating of equipment etc. Also presence of non-linear loads such as UPS, SMPS, speed drives etc. causes the generation of current harmonics in power system. They draw reactive power components of current from the AC mains, hence causing disturbance in supply current waveform. Thus to avoid the consequences of harmonics we have to compensate the harmonic component in power utility system. Among various method used, one of the effective method to reduce harmonic in power system is the use of Shunt Active Power Filter (SAPF). This Paper gives detail performance analysis of SAPF under two current control strategy namely, instantaneous active and reactive power theory (p-q) and synchronous frame reference theory (d-q) and their comparative analysis to justify one of the method better over other. In both method a reference current is generated for the filter which compensate either reactive power or harmonic current component in power system. In this paper, a current controller known harmonic current controller is described which is used provide corrective gating sequence of the IGBT inverter and thus helps to remove harmonics component.

CHAPTER 1

INTRODUCTION

1.1 Background

Power electronic switching device in conjunction with nonlinear loads causes serious harmonic problem in power system due to their inherent property of drawing harmonic current and reactive power from AC supply mains. They cause voltage unbalance and neutral currents problem in power system. With the distortion of current and voltage waveform due to presence of harmonic effect the power system equipment that are connected to maintain steady and reliable power flow in the power system. Major effects include overheating, capacitor failure, vibration, resonance problem, low power factor, overloading, communication interference and power fluctuation. Thus to improve the performance it is required to eliminate harmonics from power utility system [1]. One of the method used for elimination is the use of shunt active power filter (SAPF) in which a reference current is generated to remove distortion from the harmonic currents. Shunt active power filter continuously monitor the harmonics current and reactive power flow in the network and generate reference current from distorted current waveform. Thus dynamic closed loop action of SAPF helps the reduction of harmonics and compensation of reactive power in real time basis with little time delay. SAPF can be used with different current control strategy such as d-q method, fuzzy logic controller, p-q method, neural networks etc. which is helpful in removing effective harmonic from power system.

1.2 Motivation of Project Work

Harmonic pollution is mostly common in low voltage side due to wide use of nonlinear loads (UPS, SMPS, Rectifier etc.), which is undesirable as it cause serious voltage fluctuation and voltage dip in power system. So it required to eliminate undesirable current and voltage harmonics and to compensate the reactive power to improve the performance and operation of the power system. The use of traditional passive filter in removing harmonics is not that much effective because their static action and no real time action or dynamic action is taken for the removal of harmonics. But the shunt active power filter on the other hand gives promising results when compared with conventional active and passive filters. This project basically shows the comparison between two current control strategy [8] i.e. synchronous frame reference method and instantaneous active-reactive power method which is helpful to reduce the current harmonics when used with SAPF through MATLAB simulation and modeling.

1.3 Objectives of Project Work

The main objectives of this project are

- ❖ To give a brief overview about the cause and effect of harmonics in power system
- ❖ To study different types proposed filter used to eliminate harmonics from the power system.
- ❖ To study and implement different control strategies already proposed for modeling of 3 phase shunt active power filter
- ❖ To model and simulate three phase shunt active power filter with different current control strategy in MATLAB/SIMULINK environment
- ❖ To compare different control strategies based on FFT analysis (an important tool for harmonic behavioral analysis) for harmonic elimination in power system network.

CHAPTER 2

HARMONICS AND HARMONIC COMPENSATION SCHEMES

2.1 Source of Harmonics

Harmonics are usually defined as periodic steady state distortions or deterioration of original voltage and/or current waveforms in power systems where frequency of harmonic wave is an integral multiple of fundamental frequency. Major sources of voltage and current harmonic generation in power system are

- Controlling action of power electronic devices such as chopper, inverter etc. cause imbalance in power system leading to harmonic generation.
- Non-linear load such as UPS, SMPS, battery charger.
- Power electronic converter such as high-voltage direct-current power converters, traction and power converters, wind and solar-powered dc/ac converters etc. [5] cause harmonic generation owing to their energy conversion and controlling action.
- Heating material in ac/dc converters acts as a nonlinear load whose controlling action produces harmonics [5] due to inherent property of high reactive power requirement.

2.2 Effect of Harmonics

Harmonics may cause interference and disturbance in power systems network. Some of the major problems include:

- Harmonic currents present in the power system causes heating of equipment, such as transformers and generators and give huge copper loss.
- In generators owing to multiple zero crossings of distorted current waveform causes voltage instability and voltage fluctuation.
- Since frequency of harmonic current is different from that of fundamental may cause improper breaker and switch operation which is undesirable.

2.3 Harmonic Mitigation Techniques

Harmonic elimination techniques are used to improve the power system performance with some objectives

- To improve the system power factor and to compensate the reactive power.
- To maintain a particular THD limit in current harmonic distribution.

Hence various devices and equipment serves the purpose of harmonic elimination from power system. Some of widely used equipment are:

1) Line reactors (Inductive reactor)
2) Isolation transformers (provide isolation of high power circuit from low power circuit)
3) K-Factor or harmonic mitigating transformers
4) Phase shifting transformer
5) Harmonic filters

But mostly current harmonic filters are used to reduce current harmonics in power system. There are generally two types of harmonic filters are present: i) passive filter and ii) active filters.

2.3.1 Passive Filter

It is a combination of series/parallel connection of passive elements such as capacitors, inductors and/or resistor. They provide a low resistance path for the harmonic current to flow owing to the formation of resonance at that particular harmonic frequency. Hence harmonic current is diverted through passive filter network and system current becomes distortion free. Likewise distortion in voltage waveform is also removed. For bypassing the current effective means of connection is connecting the passive filter in parallel with the load. In order to improve power factor passive filters are designed as capacitive filter so that it correct the current displacement factor and provide reactive power to the load.

Different variety of passive filters such as single tuned, double tuned, high pass and c-type filters are used for harmonic mitigation purpose but among them most commonly used filter is single tuned filter. It comprises of series combination of inductor and capacitor which provide low impedance for tuned harmonics while resonating at tuning frequency.

2.3.1.1 Advantages of Passive Filters

Although passive filters doesn't eliminate harmonics to a greater extent yet it is used due to some prominent features which are described as under

1. They are simpler to configure and construct.
2. Low initial & maintenance cost (compared to APF)
3. Shunt passive filters of capacitive nature provide reactive power to the nonlinear load and on the other hand improve power factor by improving current displacement factor.
4. Lowering of THD in line current to a permissible limit can be possible by use of passive filter.

2.3.1.2 Disadvantages of Passive Filters

Some major drawbacks with passive current filters are:

1. Property and characteristics of filter depends on source impedance (i.e. impedance of the system and its topology) which are subjected to variations due to external condition.
2. Resonating condition in the filter may create problem with loads and network leading to voltage fluctuation.
3. It basically able to remove some particular harmonic components through tuning whenever the magnitude of those harmonic component is constant and pf of the system is low.
4. Filter response is static i.e. if load variation introduce some new harmonic components then the filter have to redesigned which increases the maintenance and operation cost of the

filter.

5. Load unbalancing or neutral shifting problems can't be solved.

2.3.2 Active Filter

An active filter consists of serial/parallel array of arrangement of both active and passive components and it is a type of analog electronic filter. Basic building block of active filter are Amplifiers. Thus filter performance and response is improved by the use of amplifiers instead of inductors that are used in passive filter for the same purpose. Active filter have dynamic response and thus can remove current distortion, current harmonics etc. faster than passive filter. It can also be used for reactive power compensation and also for voltage based distortions such as flickering, voltage dip, unbalancing. It uses PWM techniques to remove load unbalancing and neutral shifting problems. There is no possibility of resonating condition as tuning of frequency isn't taking place in active filtering, so the power system network remain more stable during operation. Unlike passive filter, there performance doesn't depends on system parameters and its topology.

2.3.2.1 Operation of Active Filters

Active Filter generate compensating current signal by continuously monitoring the load current with the help of some algorithm such as p-q theory, d-q transform, sliding mode control, DSP based algorithm etc. Now the generated compensating current is used to generate the switching pulse and switching sequence of IGBT inverter with the help of hysteresis controller or any other type of current controller. The inverter then generate the required harmonic current for the load through charging and discharging of DC link capacitor and injected into the system through coupling transformer with a phase difference to compensate the reactive power coming from the AC mains.

Major types of Active filters are: i) Series AF, ii) Shunt AF and iii) Hybrid AF.

2.3.2.2 Advantages of Active Filters

1. Widely compensated the THD in source current waveform.
2. Only a single filter can be able to eliminate all the unwanted harmonics.
3. Resonance condition is absent which increase the stability of power system.
4. Filter characteristics changes with load variation due to dynamic response of the filter.

CHAPTER-3

LITERATURE REVIEW

3.1 Shunt Active Power Filter

As the name depicts the shunt active power filter (SAPF) are connected in parallel to the power system network wherever a source of harmonic is present. Its main function is to cancel out the harmonic or non-sinusoidal current produce as a result of presence of nonlinear load in the power system by generating a current equal to the harmonic current but off opposite phase i.e. with 180^o phase shift w.r.t to the harmonic current. Generally SAPF uses a current controlled voltage source inverter (IGBT inverter) which generates compensating current (i_c) to compensate the harmonic component of the load line current and to keep source current waveform sinusoidal. Basic arrangement of SAPF is shown in figure 1 through block model.

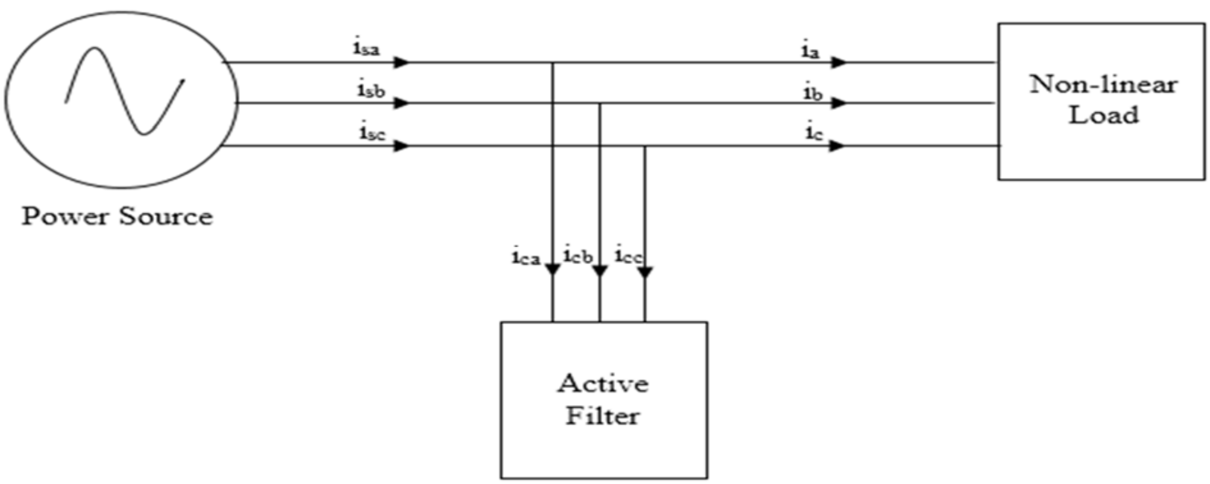

Figure.1 Shunt Active Power Filter

Compensating harmonic current in SAPF can be generated by using different current control strategy to increase the performance of the system by mitigating current harmonics present in the load current. Various current control method [2]-[4] for SAPF are discussed below.

3.2 Instantaneous Real and Reactive Power Theory (p-q method)

This theory takes into account the instantaneous reactive power arises from the oscillation of power between source and load and it is applicable for sinusoidal balanced/unbalanced voltage but fails for non-sinusoidal voltage waveform. It basically 3 phase system as a single unit and performs Clarke's transformation (a-b-c coordinates to the α-β-0 coordinates) over load current and voltage to obtain a compensating current in the system by evaluating instantaneous active and reactive power of the network system.

The p-q method control strategy in block diagram form is shown in figure 2

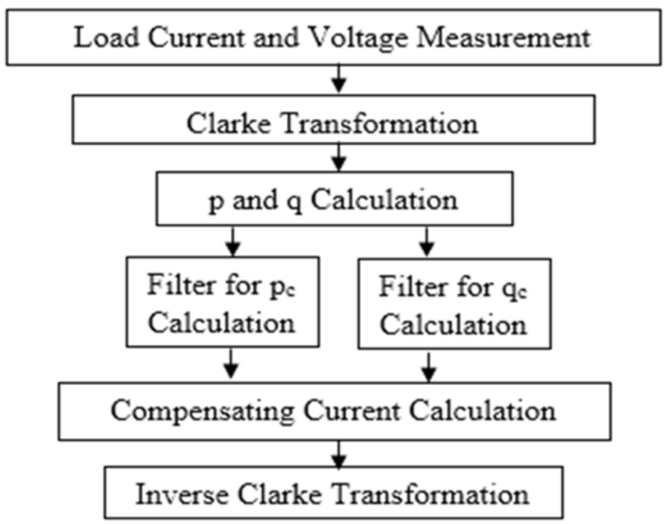

Figure.2 P-Q method control strategy

This theory works on dynamic principal as its instantaneously calculated power from the instantaneous voltage and current in 3 phase circuits. Since the power detection taking place instantaneously so the harmonic elimination from the network take place without any time delay as compared to other detection method.

Although the method analysis the power instantaneously yet the harmonic suppression greatly depends on the gating sequence of three phase IGBT inverter which is controlled by different current controller such as hysteresis controller, PWM controller, triangular carrier current controller. But among these hysteresis current controlled method is widely used due to its robustness, better accuracy and performance which give stability to power system.

3.3 Hysteresis Current Controller

Hysteresis current control method is used to provide the accurate gating pulse and sequence to the IGBT inverter by comparing the current error signal with the given hysteresis band. As seen in figure 3 the error signal is fed to the hysteresis band comparator where it is compared with hysteresis band, the output signal of the comparator is then passed through the active power filter to generate the desired compensating current that follow the reference current waveform.

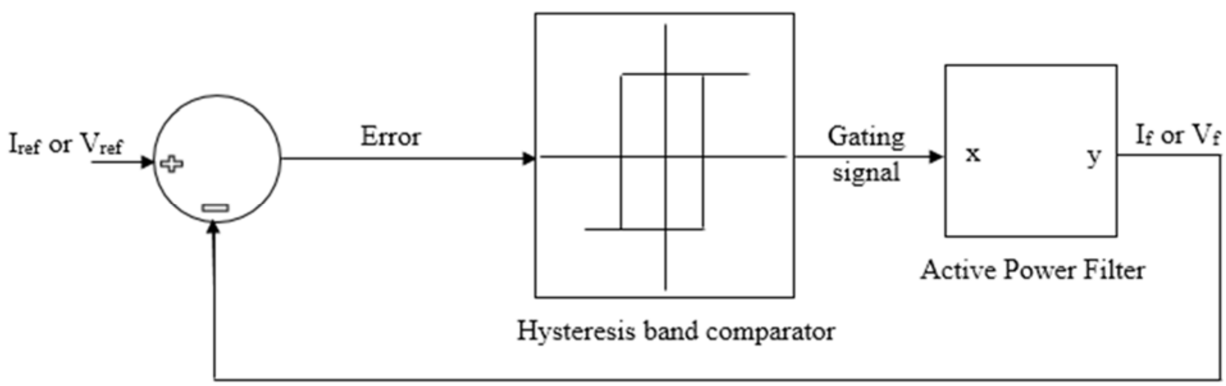

Figure.3 Hysteresis Controller control logic

Asynchronous control of inverter switches causes the current of inductor to vary between the given hysteresis band, where it is continuously compare with the error signal, hence ramping action of the current takes place. This method is used because of its robustness, excellent dynamic action which is not possible while using other type of comparators.

There are two limits on the hysteresis band i.e. upper and lower band and current waveform is trapped between those two bands as seen from figure 4. When the current tends to exceed the upper band the upper switch of the inverter is turned off and lower switch is turned so that the current again tracks back to the hysteresis band. Similar mechanism is taking place when current tends to cross the lower band. Thus current lie within the hysteresis band and compensating current follow the reference current.

Hence, Upper limit hysteresis band= I_{ref} + max(I_e) and where, I_{ref} = Reference Current

Lower limit hysteresis band= I_{ref} - min(I_e) I_e = Error Current

As a result, the hysteresis bandwidth= $2*I_e$.

Thus smaller the bandwidth better the accuracy.

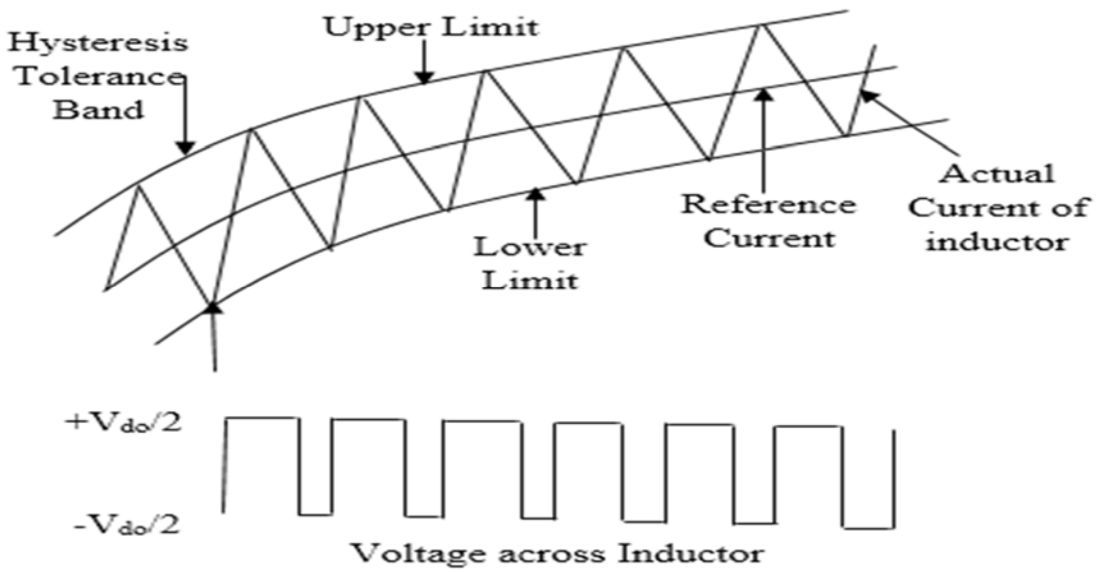

Figure.4 Hysteresis Band

Switching frequency can be easily determined by looking at the voltage waveform of the inductor. The voltage across inductor depends on gating sequence/gating pulse of IGBT inverter which is again dependent on the current error signal of the hysteresis controller. Variable frequency can be obtained by adjusting the width of the hysteresis tolerance band.

3.3 Synchronous Reference Frame theory (d-q method)

Another method to separate the harmonic components from the fundamental components is by generating reference frame current by using synchronous reference theory. In synchronous reference theory park transformation is carried out to transformed three load current into synchronous reference current to eliminate the harmonics in source current. The main advantage of this method is that it take only load current under consideration for generating reference current and hence independent on source current and voltage distortion. A separate PLL block it used for maintaining synchronism between reference and voltage for better performance of the system. Since instantaneous action is not taking place in this method so the method is little bit slow than p-q method for detection and elimination of harmonics. Figure 5 illustrate the d-q method with simple block diagram.

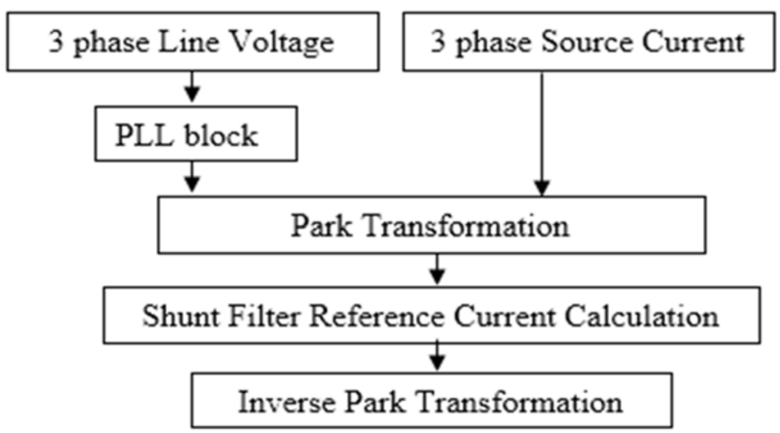

Figure.5 D-Q method control strategy

CHAPTER-4

MATHEMATICAL MODELLING

4.1 P-Q method Mathematical modelling

The relation between load current & voltage of three phase power system and the orthogonal coordinates (α-β-0) system are expressed by Clarke's transformation which is shown by the following equations 1 & 2.

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \text{.......... (1)}$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \text{.......... (2)}$$

In orthogonal co-ordinate system instantaneous power can be found out by simply multiplying the instantaneous current with their corresponding instantaneous voltage. Here the 3 phase co-ordinate system (a-b-c) is mutually orthogonal is nature, so we can found out instantaneous power as in the form of equation 3.

$$p = v_a i_a + v_b i_b + v_c i_c \text{ .... (3)}$$

From above equations, the instantaneous active and reactive power in matrix form can be rewritten as

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \text{............ (4)}$$

The instantaneous reactive power produces an opposing vector with 180° phase shift in order to cancel the harmonic component in the line current. From the above equations, yield equation 5.

$$\begin{bmatrix} i_{s\alpha}^* \\ i_{s\beta}^* \end{bmatrix} = \frac{1}{V_\alpha^2 + V_\beta^2} \begin{bmatrix} V_\alpha & -V_\beta \\ V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} P_o + P_{loss} \\ 0 \end{bmatrix} \text{....... (5)}$$

After finding the α-β reference current, the compensating current for each phase can be derived by using the inverse Clarke transformations as shown in equation 6.

$$\begin{bmatrix} i_{ca}^* \\ i_{cb}^* \\ i_{cc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \end{bmatrix} \ldots\ldots\ldots (6)$$

4.2 D-Q method Mathematical modelling

According to Park's transformation relation between three phase source current (a-b-c) and the d-q reference co-ordinate current is given by equation 7

$$\begin{bmatrix} i_{ld} \\ i_{lq} \\ i_{l0} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos \mu & \cos(\mu - \frac{2\pi}{3}) & \cos(\mu + \frac{2\pi}{3}) \\ -\sin \mu & -\sin(\mu - \frac{2\pi}{3}) & -\sin(\mu + \frac{2\pi}{3}) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_{la} \\ i_{lb} \\ i_{lc} \end{bmatrix} \ldots\ldots\ldots\ldots (7)$$

Where, 'μ' is the angular deviation of the synchronous reference frame from the 3 phase orthogonal system which is a linear function of fundamental frequency. The harmonic reference current can be obtained from the load currents using a simple LPF. The currents in the synchronous reference system can be decomposed into two components given by equation 8 & 9

$$i_{ld} = i_{\bar{ld}} + i_{\tilde{ld}} \ldots\ldots\ldots (8)$$

$$i_{lq} = i_{\bar{lq}} + i_{\tilde{lq}} \ldots\ldots\ldots (9)$$

After filtering DC terms ($i_{\bar{lq}}$, $i_{\bar{ld}}$) are suppressed and alternating term are appearing in the output of extraction system which are responsible for harmonic pollution in power system. The APF reference currents is given by equation 10

$$\begin{bmatrix} i_{fd}^* \\ i_{fq}^* \end{bmatrix} = \begin{bmatrix} i_{\tilde{ld}} \\ i_{\tilde{lq}} \end{bmatrix} \ldots\ldots\ldots (10)$$

In order to find the filter currents in three phase system which cancels the harmonic components in line side, the inverse Park transform can be used as shown by equation 11

$$\begin{bmatrix} i_{fa}^* \\ i_{fb}^* \\ i_{fc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos \mu & -\sin \mu \\ \cos(\mu - \frac{2\pi}{3}) & -\sin(\mu - \frac{2\pi}{3}) \\ \cos(\mu + \frac{2\pi}{3}) & \sin(\mu + \frac{2\pi}{3}) \end{bmatrix} \begin{bmatrix} i_{fd}^* \\ i_{fq}^* \end{bmatrix} \ldots\ldots\ldots\ldots (11)$$

CHAPTER-5

MATLAB/SIMULINK

MODELLING

5.1 Power system Simulink model with Shunt APF and Non-linear load

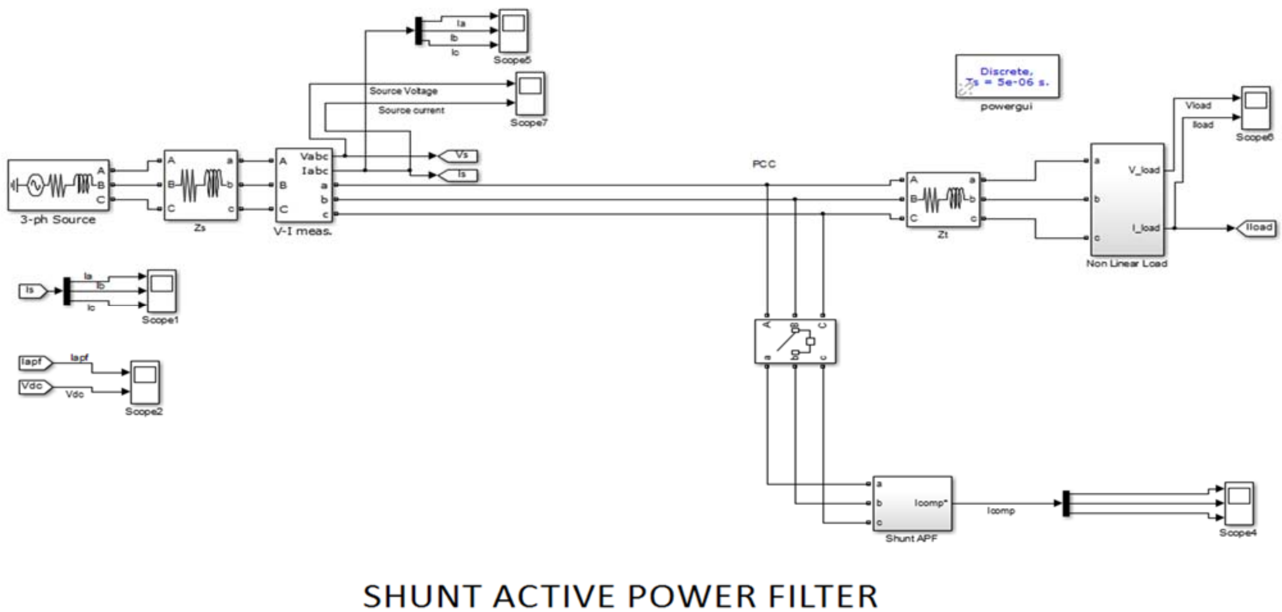

Figure. 6 System model with filter

5.2 Simulink model of Shunt APF with p-q method

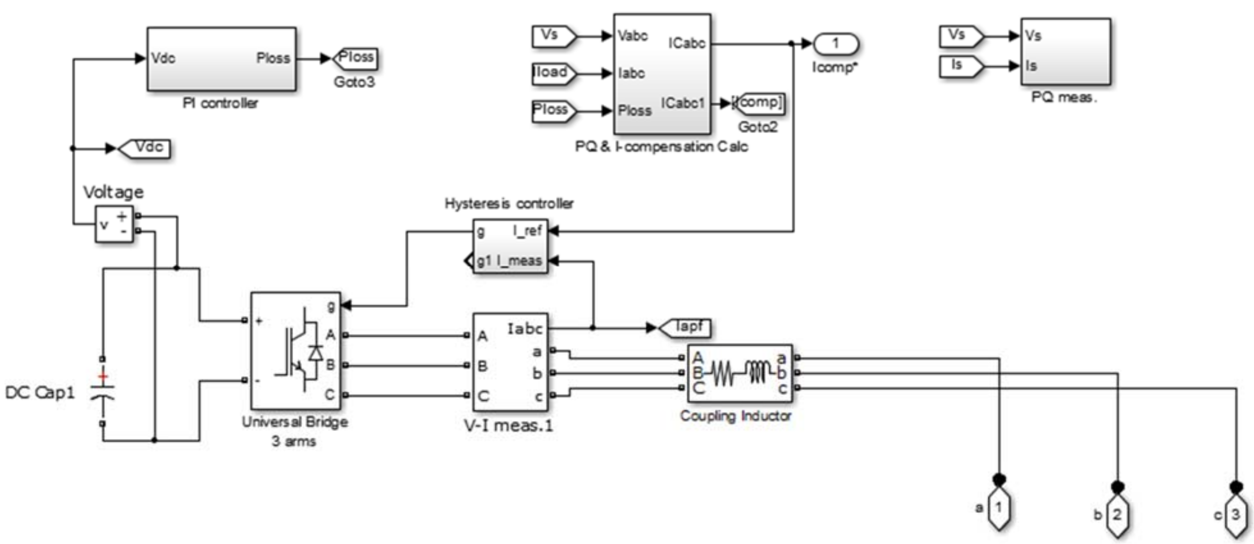

Figure.7 Model of Shunt APF with p-q method

5.3 Simulink model of Shunt APF with d-q method

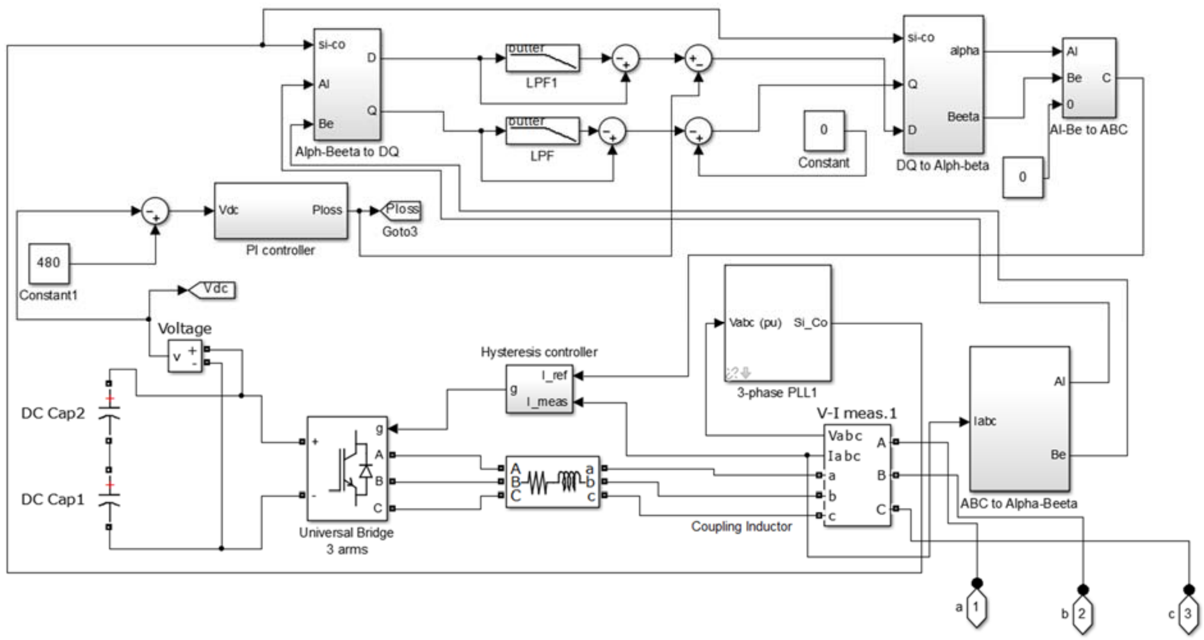

Figure.8 Model of Shunt APF with d-q method

5.4 Design Parameters for MATLAB Simulation

Simulation is performed on **a balanced Non –Linear Load** consisting of an R-L load and a bridge rectifier as shown below:

- System Parameters

Source Voltage (r.m.s)	400Volt
System Frequency	50Hz

Table.1 System parameter specification

- Active Power Filter (APF) Parameters

Coupling Inductance	1mH
Coupling Resistance	0.01Ω
Dc link capacitance	1100μF
Source inductance	0.05mH
Source resistance	0.1Ω
Load resistance	0.001Ω
Load inductance	1μH

Table.2 SAPF parameter specification

CHAPTER-6

SIMULATION RESULT

AND COMPARISON

6.1 Simulink Result

The simulation result were obtained by in MATLAB/Simulink environment using Sim-power system Toolbox. Here a breaker is used to show the analysis during ON & OFF time of the Active power Filter. A slight distortion in current and voltage waveform is seen during switching of breaker which can be removed by using thermistor in series with DC link capacitor.

6.1.1 Simulink Result with P-Q control strategy

Breaker Transition Time: - 0.06 sec **Simulation Run Time**: - 0.2 sec

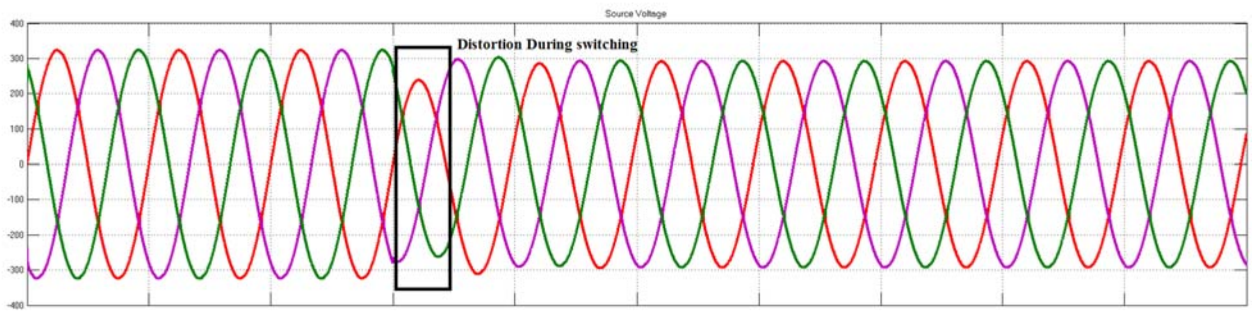

Figure.9.1 Source Voltage Waveform before and after filtering with p-q method

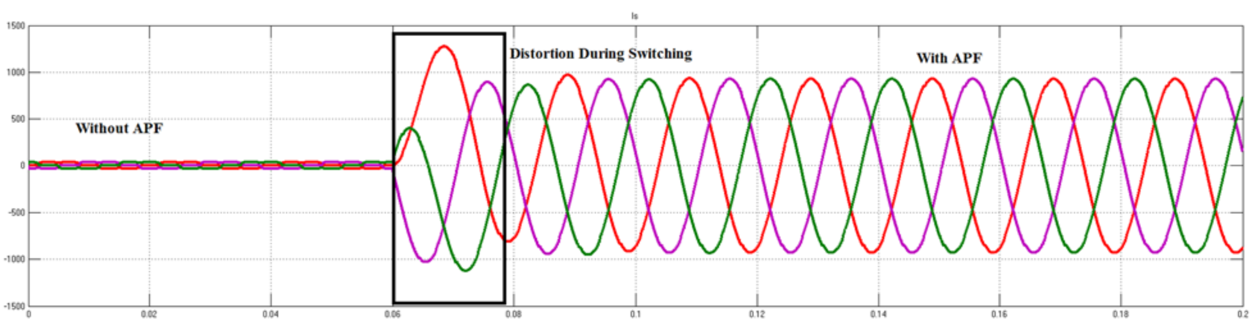

Figure.9.2 Source Current Waveform before and after filtering with p-q method

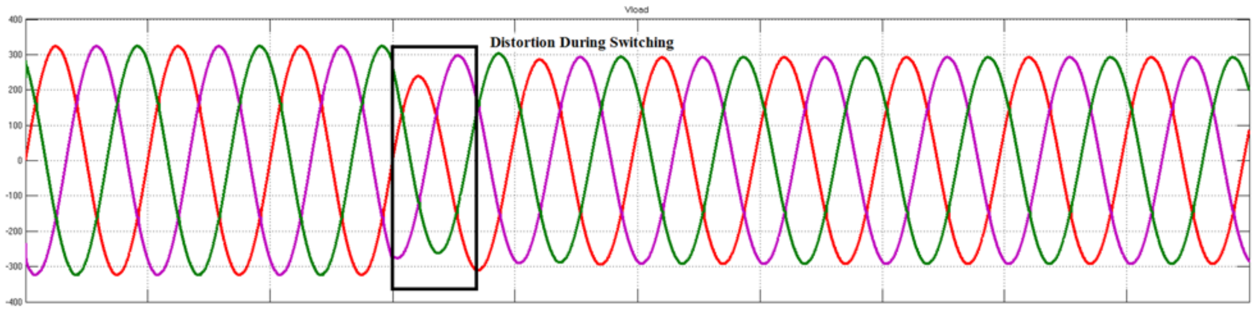

Figure.9.3 Load Voltage Waveform before and after filtering with p-q method

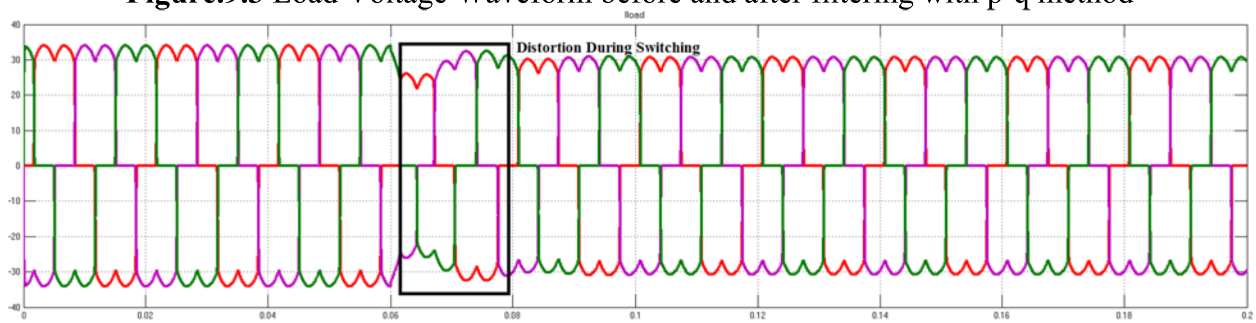

Figure.9.4 Load Current Waveform before and after filtering with p-q method

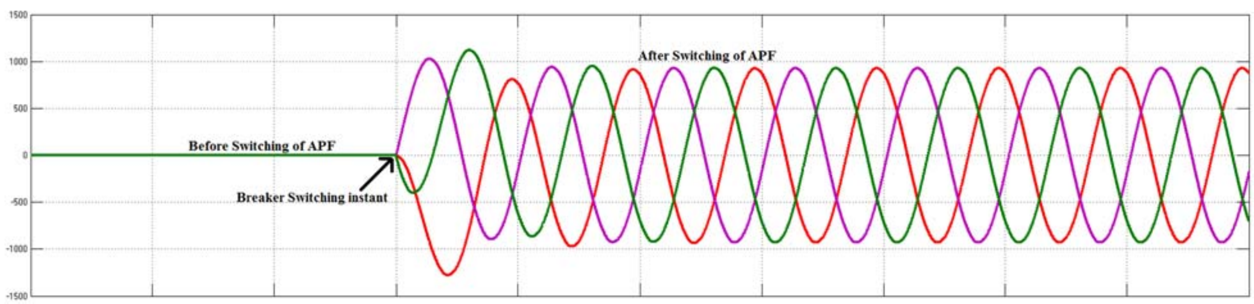

Figure.9.5 APF Current Waveform before and after filtering with p-q method

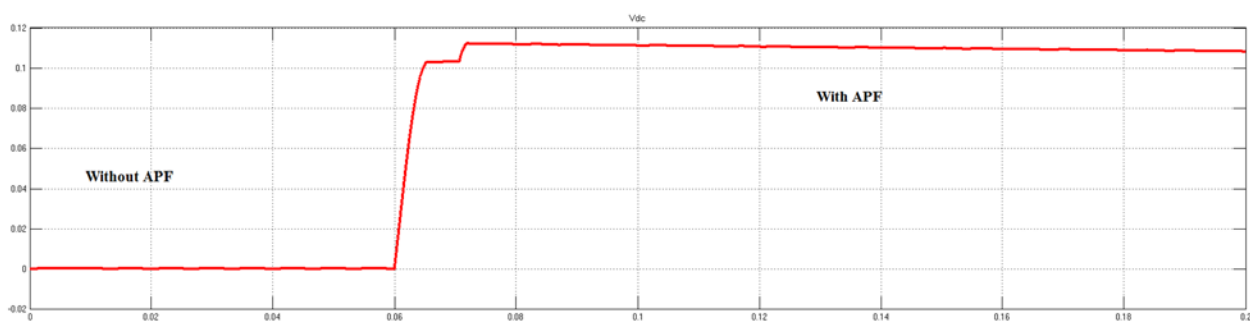

Figure.9.6 DC link Voltage Waveform before and after filtering with p-q method

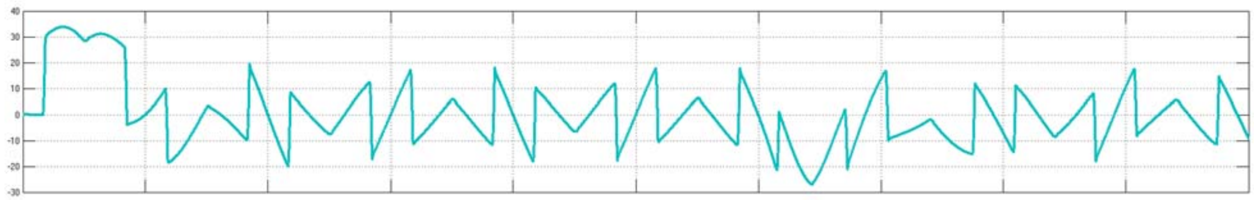

Figure.9.7 Compensating Current Waveform

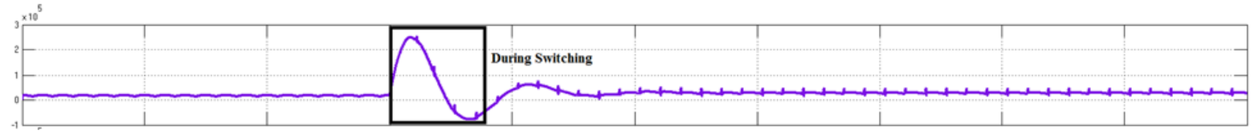

Figure.9.8 Active Power Waveform

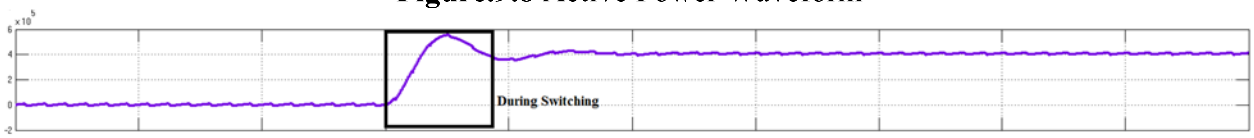

Figure.9.9 Reactive Power Waveform

6.1.2 Simulink Result with D-Q control strategy

Breaker Transition Time: - 0.08 sec **Simulation Run Time**: - 0.2 sec

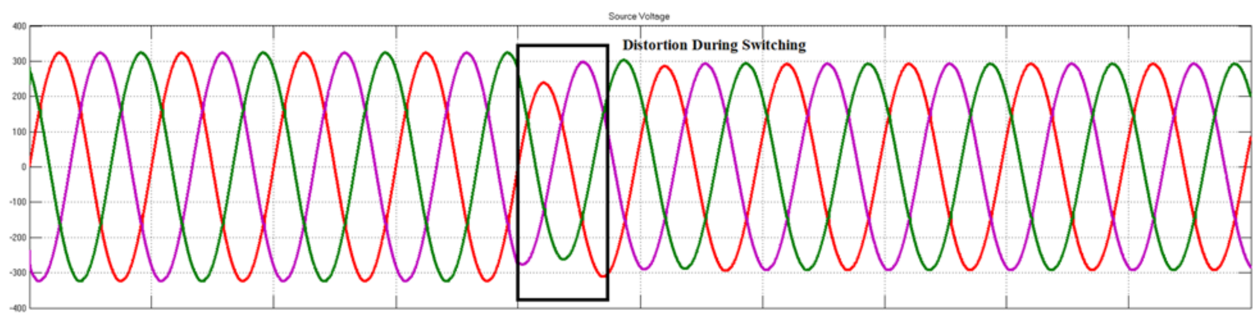

Figure.10.1 Source Voltage Waveform before and after filtering with d-q method

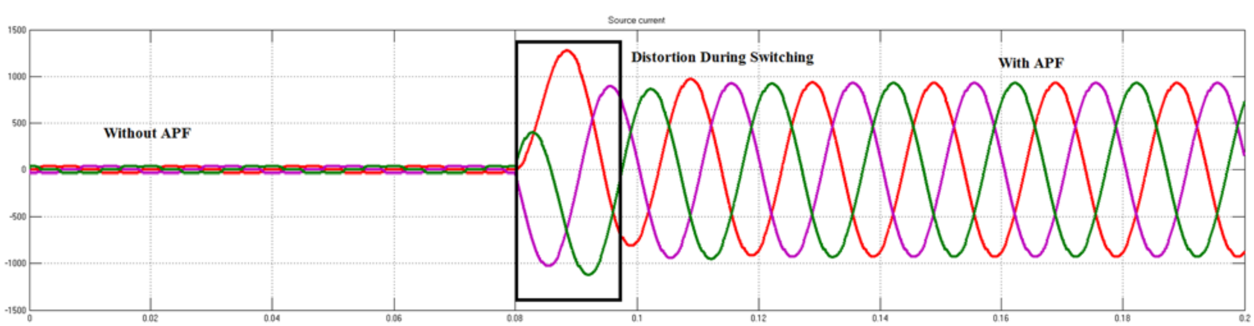

Figure.10.2 Source Current Waveform before and after filtering with d-q method

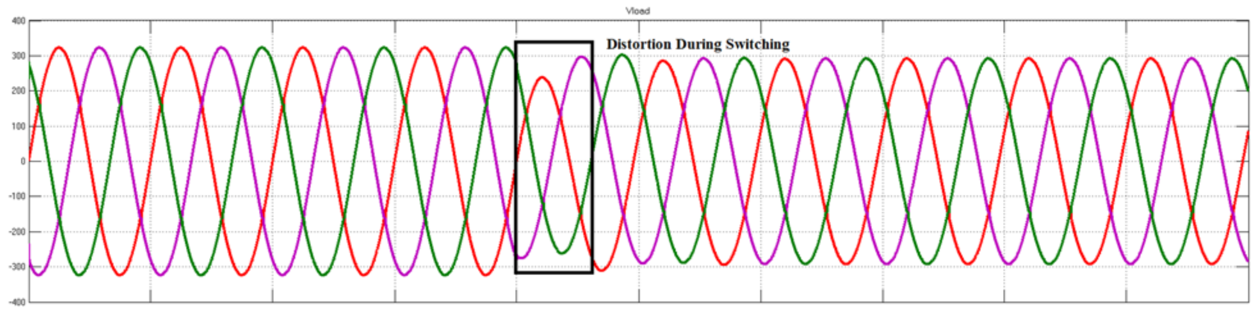

Figure.10.3 Load Voltage Waveform before and after filtering with d-q method

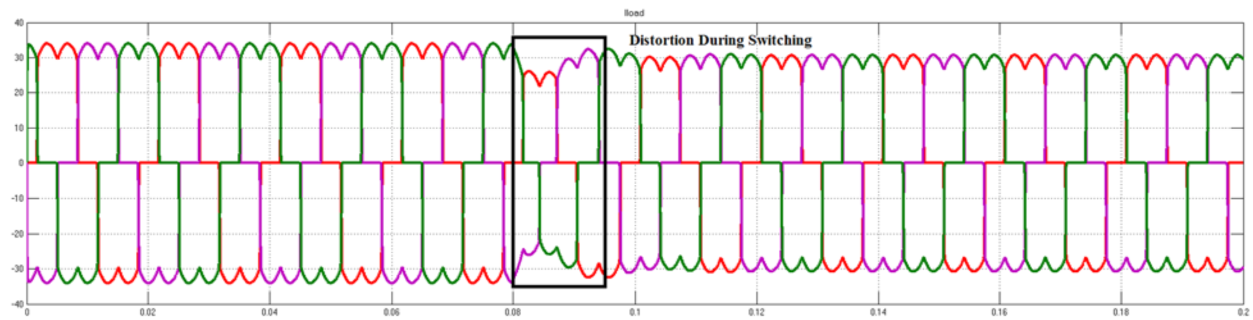

Figure.10.4 Load Current Waveform before and after filtering with d-q method

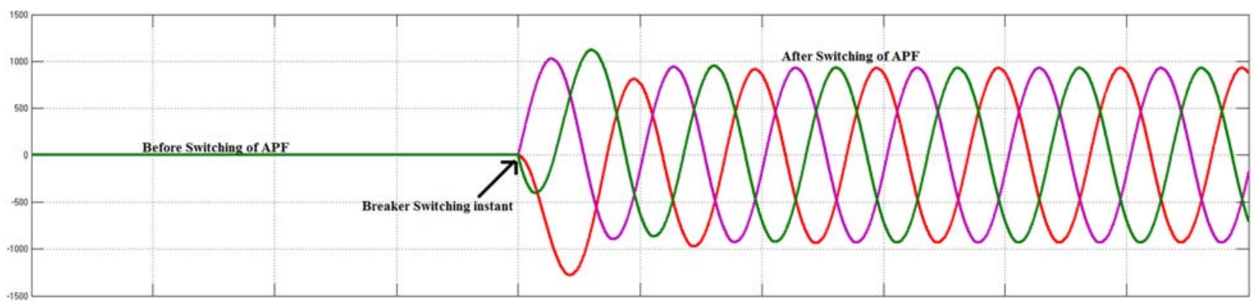

Figure.10.5 APF Current Waveform before and after filtering with d-q method

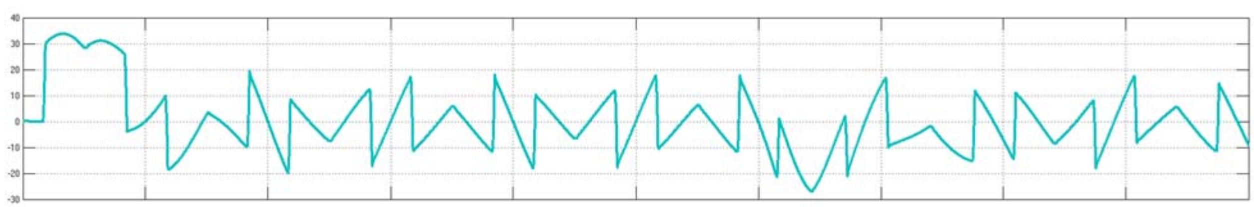

Figure.10.6 Compensating Current Waveform

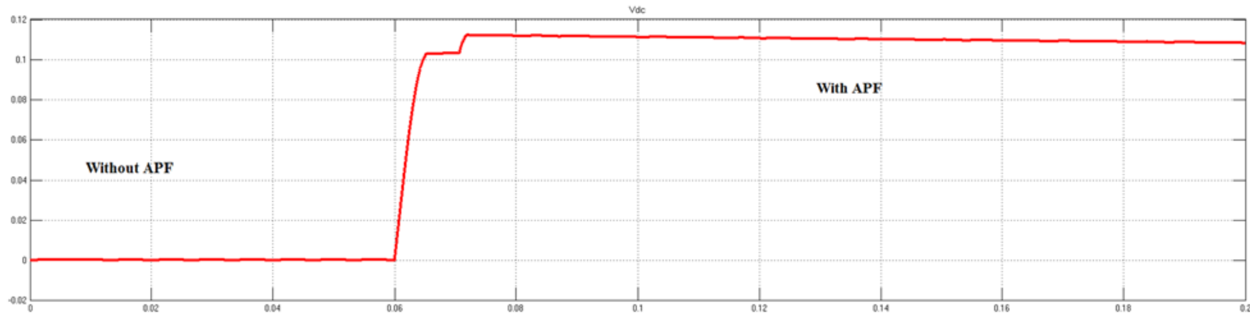

Figure.10.7 DC link Voltage Waveform before and after filtering with d-q method

6.1.3 FFT Analysis

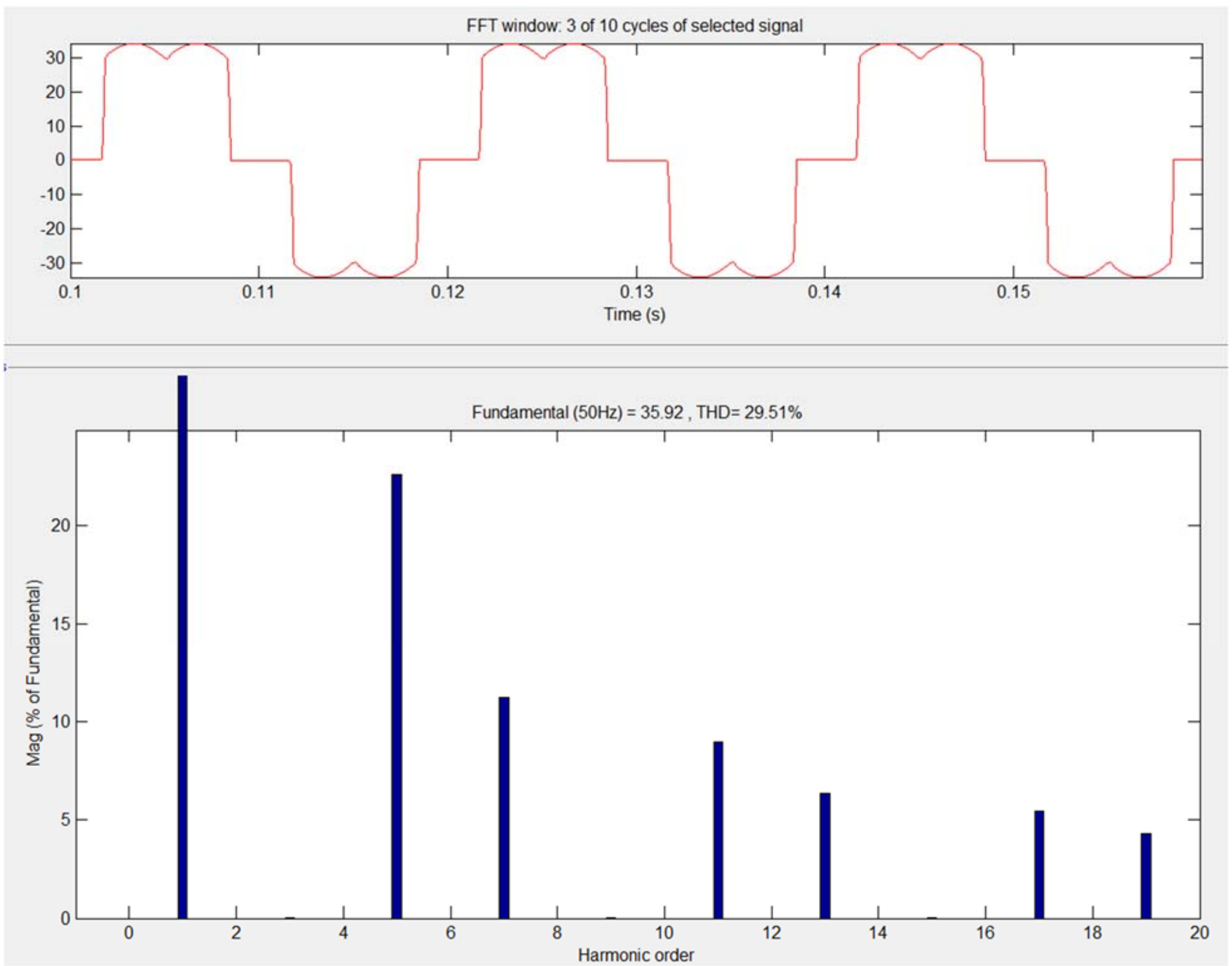

Figure.11.1 FFT analysis of source current without APF

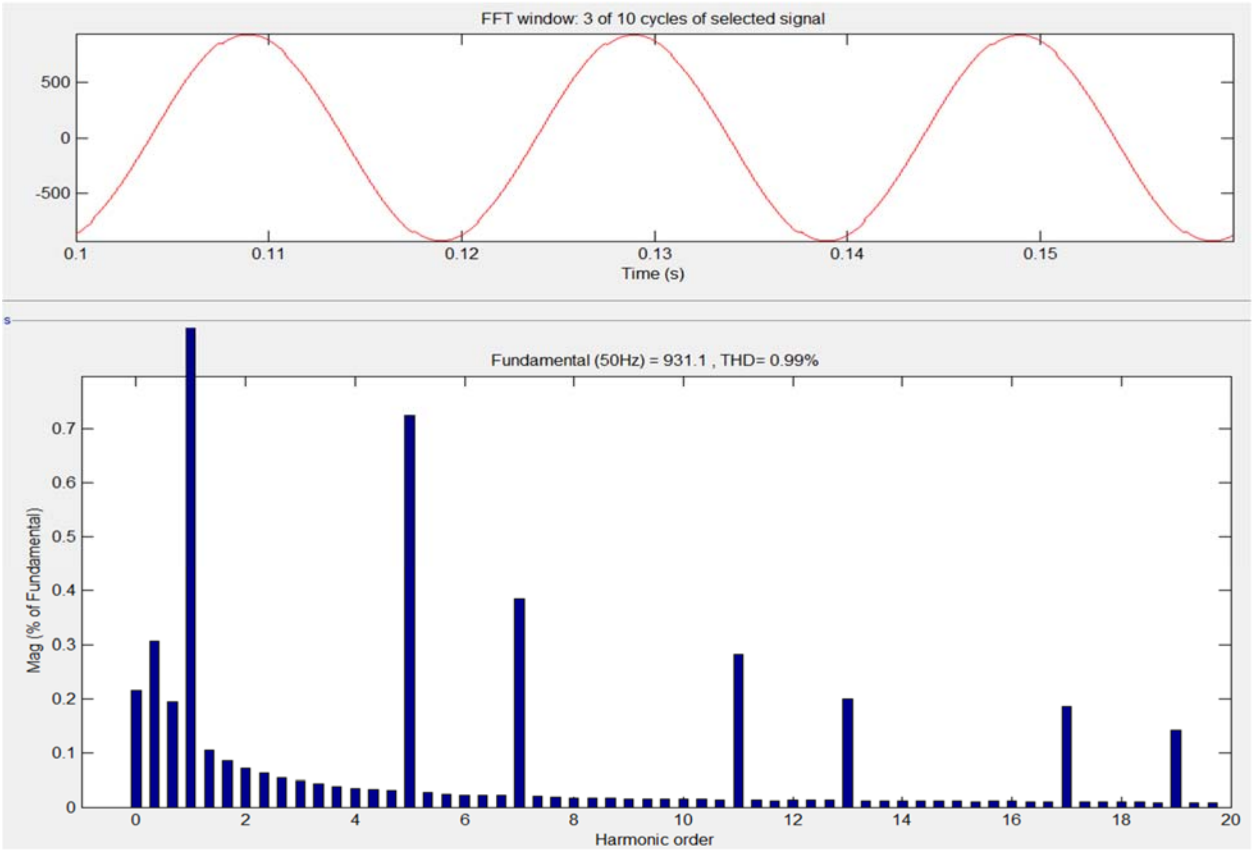

Figure.11.2 FFT analysis of source current with SAPF using p-q method

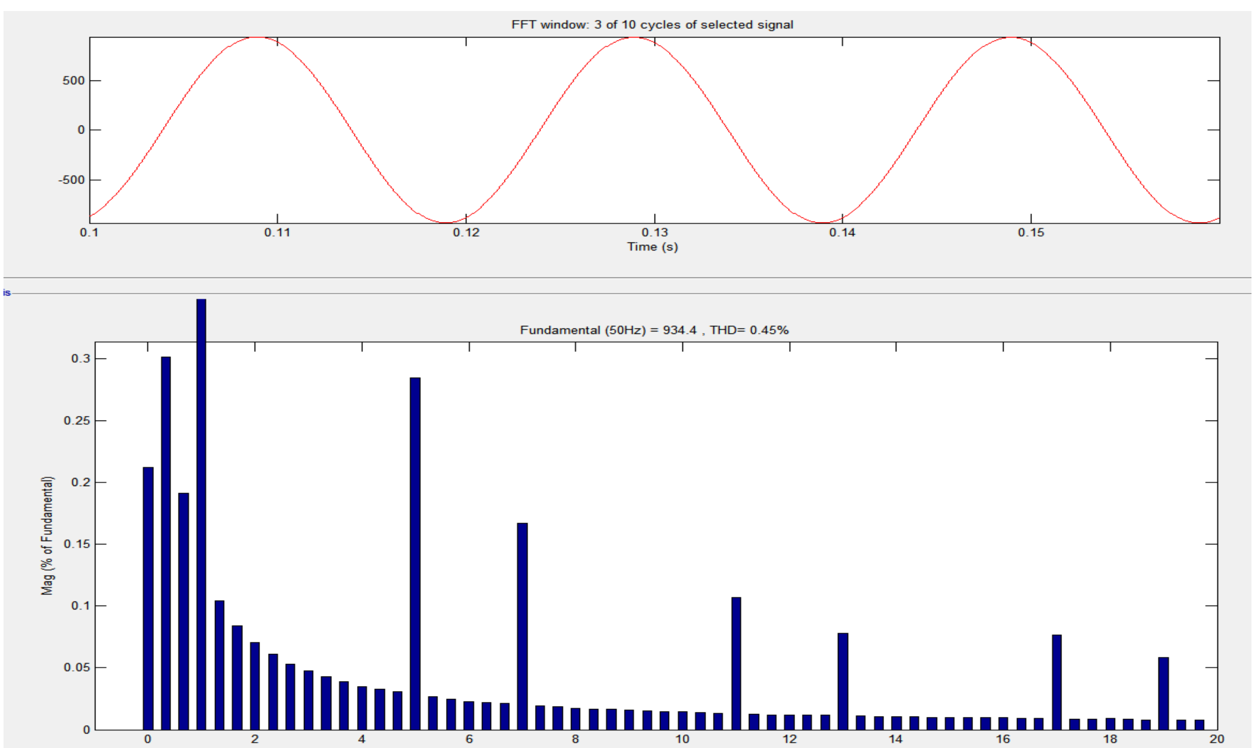

Figure.11.3 FFT analysis of source current with APF using d-q method

6.4 Comparative Analysis

The comparative analysis between system without SAPF and with SAPF using p-q & d-q current control method based on FFT analysis is shown in table 3 and 4. Table 3 shows the % of individual harmonics distortion w.r.t fundamental present in the system and table 4 shows the Total Harmonic Distortion (THD) of the system before and after using filter. As seen from the table 3 and 4 the system with SAPF having d-q control strategy gives the better result as compare to the system without filter & SAPF with p-q control strategy.

Harmonic Order	System without SAPF	System with SAPF using 'p-q' method	System with SAPF using 'd-q' method
3rd order	0.03%	0.09%	0.06%
5th order	23%	0.75%	0.28%
7th order	11%	0.35%	0.16%
9th order	0.03%	0.04%	0.03%
11th order	9%	0.30%	0.12%
13th order	7%	0.26%	0.08%
15th order	0.03%	0.01%	0.01%
17th order	6%	0.24%	0.08%
19th order	5%	0.17%	0.07%

Table.3 Harmonic component as % of fundamental frequency component

System	System without SAPF	System with SAPF using 'p-q' method	System with SAPF using 'd-q' method
% THD	29.51%	0.99%	0.45%

Table.4 Total Harmonic Distortion of System with and without filter

6.4 Graphical Comparison

Graph shown in figure 12 summarize the performance of the distribution system without and with shunt active power filter using ‘p-q’ & ‘d-q’ current control strategies.

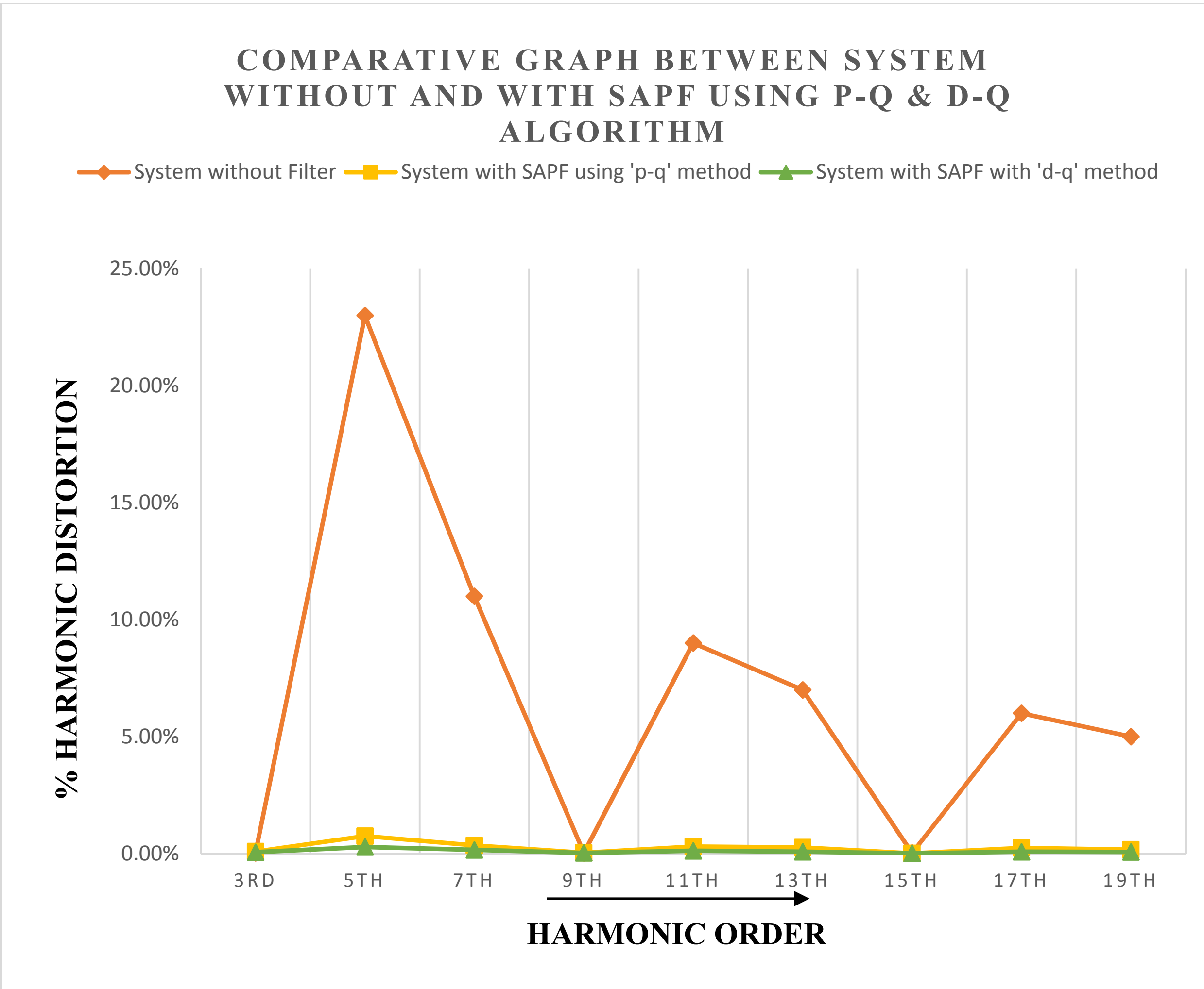

Figure.12.1 Comparative Graphical analysis between System without and with SAPF

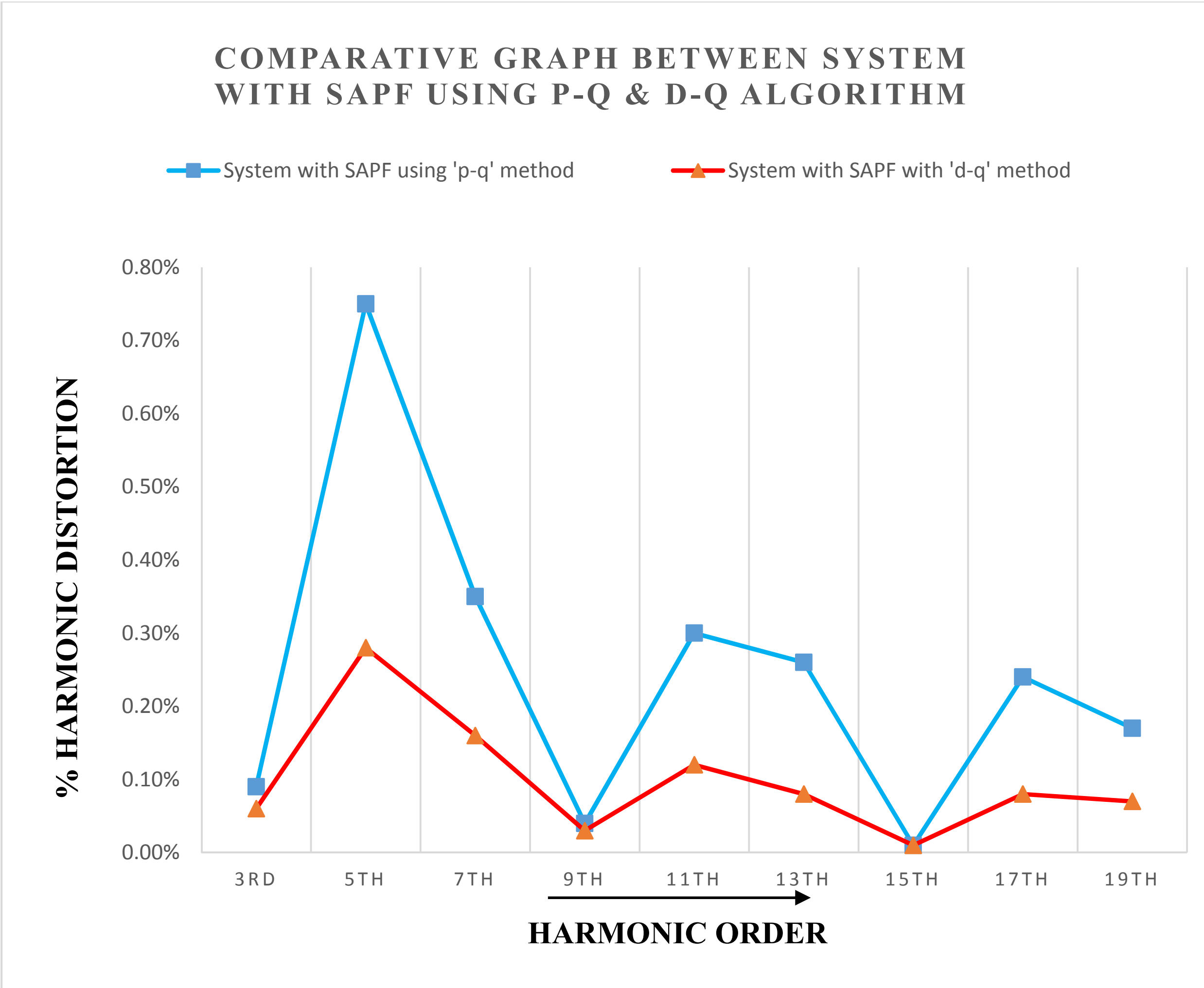

Figure.12.2 Comparative Graphical analysis between p-q and d-q method

CHAPTER-7

COMPONENT

DESCRIPTION

7.1 INTRODUCTION

This chapter gives a brief idea about different components required to establish the experimental set up. The different hardware requirements for experimental purpose are broadly classified into

1. Single phase Variac
2. 3 phase IGBT based inverter
3. Three phase bridge rectifier
4. Signal conditioning circuit
5. Filter inductor
6. DC link capacitor
7. R-L load

7.1.1 Single Phase Variac

It was used to provide control supplied voltage of 230 r.m.s Voltage between a phase and neutral to start the experiment

7.1.2 IGBT Based Inverter

Six IGBT are used to provide the switching phenomena in a voltage source inverter so that controlled DC voltage is obtained across the DC link capacitor. IGBT to be used are of SEMIKRON made (SKM150GB063D) having rating of 600volt, 175 ampere. These are used to form the 3 phase VSI and are driven by the gate driver card VLA517-01R.

7.1.3 Three Phase Bridge Rectifier

An uncontrolled 3 phase bridge rectifier is used along with a three phase balanced R-L load for generating current harmonics in the power system. 6 diodes are used for the construction of 3 phase uncontrolled bridge each of rating 500 volt, 15 ampere.

7.1.4 Signal Conditioning Circuit

In this section the description of the different sensors and the gate driver card for the IGBT's of the VSI are described.

7.1.4.1 Current Sensor

For experiment to be carried we required both source and load current to be sensed and there their signal should be fed to the APF. Sensing mechanism is done by current sensor. For simplicity we used two LEM made current transducer (LA 55-P) per phase. The current schematic and working principle is shown in figure 13.1.

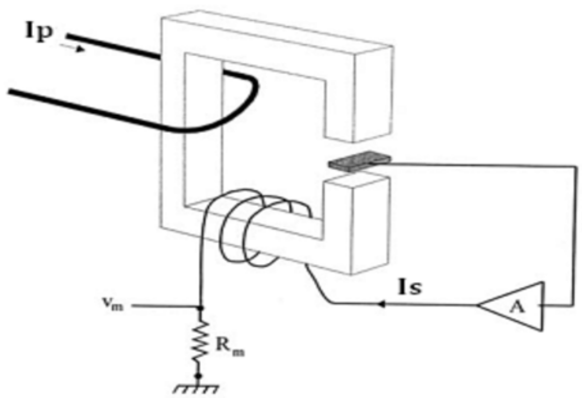

Figure.13.1 Working principle of Current Sensor

Figure.13.2 LA 55-P Current Sensor

According to the principle of transformer the primary current produced by the magnetic flux is to be balanced by the secondary flux. Here the same principle is used where primary current is balanced by secondary coil current using Hall devices and other electronic apparatus. The basic principle of transformer is given as

$$Np \times Ip = Ns \times Is \tag{12}$$

Where, N_P is number of primary turns and N_S is number of secondary turns. Turns ratio is kept constant so that the secondary current is exact replica of primary current. Voltage drop is taking place due to the resistance R_M (100 Ω) on the secondary side, and this voltage drop due to secondary current act as an output signal of the current sensor. But we have to limit the output voltage to the data acquisition card within analog limit of ±10 volt, for that a non-inverting configuration opamp is used with two resistance R_F and R_I to select the proper gain of operation. Both the opamp and current sensor require ± 15 volt supply for operation.

Two current sensor cards per phase are required for sensing

1. Source current
2. Load current

Current sensor card for measuring source current

Source current is limited to 10 A r.m.s, and thus current sensor card is designed keeping in mind the maximum limit of current output of the source current. It is calibrated such that for 1 A of source current output signal will be 2V. Using MATLAB or some other method curve fitting formula for current sensor card measuring the source current can be computed as

$$v_{out} = 2.189 \times i_{Source} - 0.1207 \text{ ………… (13)}$$

Current sensor card for measuring load current

Similarly load current is limited to a maximum value of 40 A r.m.s and for measuring this the current sensor is calibrated as 2 A of load current gives 1 V of output voltage. Using MATLAB or some other method curve fitting formula for current sensor card measuring the source current can be computed as

$$v_{out} = 2.192 \times i_{Load} + 0.1081 \text{ ………… (14)}$$

7.1.4.2 Voltage Sensor

Controller operation depends on source voltage, load voltage, DC link capacitor voltage. So the accurate measurement of the voltage is necessary for proper operation of the filter circuit. For measurement of voltage, LEM (LV 25-P) made voltage transducer used. Three voltage sensor are used for measurement of 3 different type voltages per phase. It works on the principle of Hall Effect and hence named as Hall Effect based voltage transducer. The primary voltage is generated when primary current flows through the circuit and hence magnetic flux is created when current flows through the external resistance R_{in}. This flux is known as primary flux which links with the magnetic circuit and Hall Effect device present on the secondary side produces an output voltage proportional to the flux. Now this voltage and primary current generate a secondary current with the help of external electrical circuitry which is an exact replica of primary voltage. Now the secondary current flows through the external measuring resistance R_M to generate the voltage drop fed to the Opamp LM741. Opamp is operated in non-inverting mode to provide output voltage in suitable range of ± 10 V as input to the ADC pins. Voltage transducer can be able to measure up to ± 500 V whereas it require ± 15 V supply for its operation.

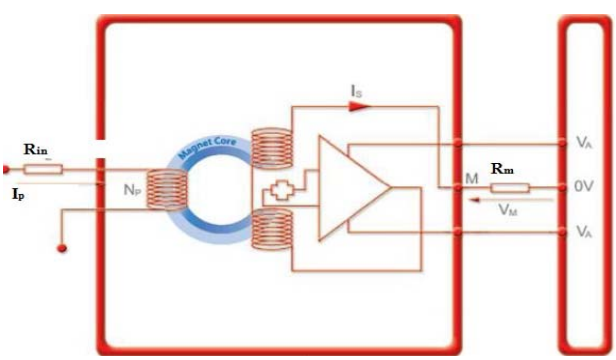

Figure.14.1 Working principle of Voltage Sensor

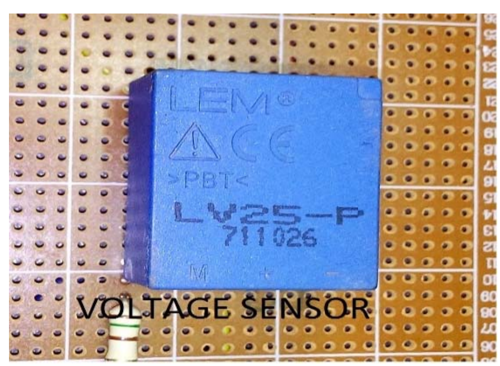

Figure.14.2 LV 25-P Voltage Sensor

Three voltage sensor cards are used for measurement of:

1. Source voltage
2. Load voltage
3. DC link capacitor voltage

All the voltage sensors are designed to measure a maximum voltage of 500V (470 V r.m.s). The input resistance used for measurement of primary voltage of the transducer considering maximum accuracy at optimal primary current of 10mA, was 50KΩ/5W. At the output side for measurement of voltage a resistance of 65KΩ/5W was placed. The sensor is calibrated in such a manner that 10 V change in input voltage results in 1V change of output voltage. . Using MATLAB or some other method curve fitting formula for Voltage sensor card are computed as:

For source voltage sensor, $v_{out} = 0.0923 \times v_{Source} + 0.2380$ …………..... (14)

For load voltage sensor, $v_{out} = 0.0904 \times v_{Load} + 0.2541$ ……………….. (15)

For DC link voltage sensor, $v_{out} = 0.0941 \times v_{DC\_Link} + 0.3541$ …………… (16)

7.1.4.3 Gate Driver

For driving the gate circuit a linkage is present between gate of IGBT inverter and hysteresis controller output known as gate driver card. For the experiment purpose high performance FUJI made hybrid IGBT driver IC, VLA517-01R is used for providing gating signal to the IGBT switches. To isolate the high power circuit from low power module an Optocoupler IC is used which provide isolation between power side and signal side of the chip. Chip input signal are logical signals with 5V as logic high and 0V as logic low which gives corresponding output of +15V and -5V. For satisfactory operation of the chip input logic signal given to the chip should be capable to handle a driving current of 10mA, for this purpose a gate series resistance (R_g=25Ω) is used across gate emitter terminals of the corresponding IGBT. The circuit schematic diagram for the IGBT driver is shown in Fig.15.1.

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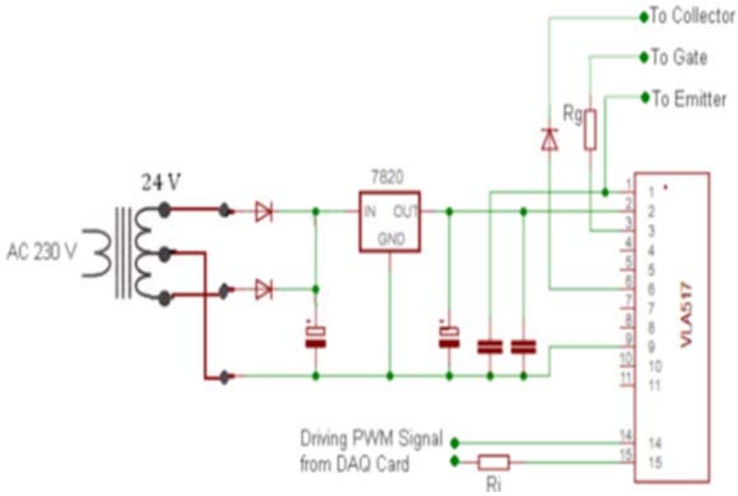

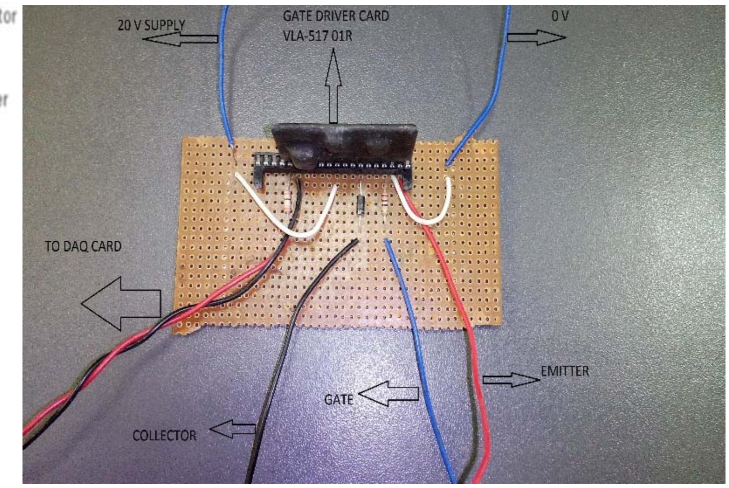

Figure.15.1 Working principle of gate driver circuit

Figure.15.2 Gate Driver Circuit

7.1.6 Filter Inductor

Main purpose of using filter inductor is to eliminate very high frequency or harmonic component from the current.

7.1.6 DC Link Capacitor

The DC link capacitor used in the inverter circuit is of 470μF (500 volt, 25 ampere) and is shown in the Fig.16.

Figure.16 DC Link Capacitor

7.1.6 R-L Load

For the experiment we consider a 3 phase R-L load whose values are adjusted with that of simulation parameters to get accurate result. A basic R-L load is shown in Fig.17.

Figure.17 R-L Load

CHAPTER-8

CONCLUSION

8.1 Conclusion and future activity

It clearly visible from the FFT analysis of the MATLAB/SIMULINK model of the circuit with and without filter that the harmonic component present in the source is compensated with use of filter. Further it is also seen that harmonic is compensated to a greater extent while using d-q control strategy instead of p-q i.e. the THD of source current is almost reduces by half while using the d-q method.

Since gate driver card and data acquisition card is not available we are unable to complete the experimental setup and validate the result coming from simulation. In future it is possible to find a better way than d-q current control method to eliminate harmonics in power utility system with maintaining reliability and stability of the system by using PWM based current controller.

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Appendix A

LEM Current Transducer (LA 55-P)

Table A1. Specification of Current Sensor

Electrical data

I_{PN}	Primary nominal r.m.s. current		50					A
I_P	Primary current, measuring range		0 .. ± 70					A
R_M	Measuring resistance @		T_A = 70°C		T_A = 85°C			
			$R_{M\,min}$	$R_{M\,max}$	$R_{M\,min}$	$R_{M\,max}$		
	with ± 12 V	@ ± 50 A $_{max}$	10	100	60	95		Ω
		@ ± 70 A $_{max}$	10	50	60[1]	60[1]		Ω
	with ± 15 V	@ ± 50 A $_{max}$	50	160	135	155		Ω
		@ ± 70 A $_{max}$	50	90	135[2]	135[2]		Ω
I_{SN}	Secondary nominal r.m.s. current		50					mA
K_N	Conversion ratio		1 : 1000					
V_C	Supply voltage (± 5 %)		± 12 .. 15					V
I_C	Current consumption		10 (@ ± 15 V) + I_S					mA
V_d	R.m.s. voltage for AC isolation test, 50 Hz, 1 mn		2.5					kV

Accuracy - Dynamic performance data

X	Accuracy @ I_{PN}, T_A = 25°C	@ ± 15 V (± 5 %)	± 0.65		%
		@ ± 12 .. 15 V (± 5 %)	± 0.90		%
ε_L	Linearity		< 0.15		%
			Typ	Max	
I_O	Offset current @ I_P = 0, T_A = 25°C			± 0.2	mA
I_{OM}	Residual current[3] @ I_P = 0, after an overload of 3 x I_{PN}			± 0.3	mA
I_{OT}	Thermal drift of I_O	0°C .. + 70°C	± 0.1	± 0.5	mA
		- 25°C .. + 85°C	± 0.1	± 0.6	mA
t_{ra}	Reaction time @ 10 % of $I_{P\,max}$		< 500		ns
t_r	Response time @ 90 % of $I_{P\,max}$		< 1		μs
di/dt	di/dt accurately followed		> 200		A/μs
f	Frequency bandwidth (- 1 dB)		DC .. 200		kHz

General data

T_A	Ambient operating temperature		- 25 .. + 85	°C
T_S	Ambient storage temperature		- 40 .. + 90	°C
R_S	Secondary coil resistance @	T_A = 70°C	80	Ω
		T_A = 85°C	85	Ω
m	Mass		18	g
	Standards[4]		EN 50178	

Appendix B

LEM Voltage Transducer (LV 25-P)

Table B1. Specification of Voltage Sensor

Electrical data

I_{PN}	Primary nominal current rms		10		mA
I_{PM}	Primary current, measuring range		0 .. ± 14		mA
R_M	Measuring resistance		$R_{M\,min}$	$R_{M\,max}$	
	with ± 12 V	@ ± 10 mA $_{max}$	30	190	Ω
		@ ± 14 mA $_{max}$	30	100	Ω
	with ± 15 V	@ ± 10 mA $_{max}$	100	350	Ω
		@ ± 14 mA $_{max}$	100	190	Ω
I_{SN}	Secondary nominal current rms		25		mA
K_N	Conversion ratio		2500 : 1000		
V_C	Supply voltage (± 5 %)		± 12 .. 15		V
I_C	Current consumption		10 (@ ± 15 V) + I_S		mA

Accuracy - Dynamic performance data

X_G	Overall accuracy @ I_{PN}, T_A = 25°C @ ± 12 .. 15 V		± 0.9		%
		@ ± 15 V (± 5 %)	± 0.8		%
ε_L	Linearity error		< 0.2		%
			Typ	Max	
I_O	Offset current @ I_P = 0, T_A = 25°C			± 0.15	mA
I_{OT}	Temperature variation of I_O	0°C .. + 25°C	± 0.06	± 0.25	mA
		+ 25°C .. + 70°C	± 0.10	± 0.35	mA
t_r	Response time [1] to 90 % of I_{PN} step		40		µs

General data

T_A	Ambient operating temperature		0 .. + 70	°C
T_S	Ambient storage temperature		- 25 .. + 85	°C
R_P	Primary coil resistance	@ T_A = 70°C	250	Ω
R_S	Secondary coil resistance	@ T_A = 70°C	110	Ω
m	Mass		22	g
	Standard		EN 50178: 1997	

Appendix C

VLA517-01R Hybrid IC for Driving IGBT Modules

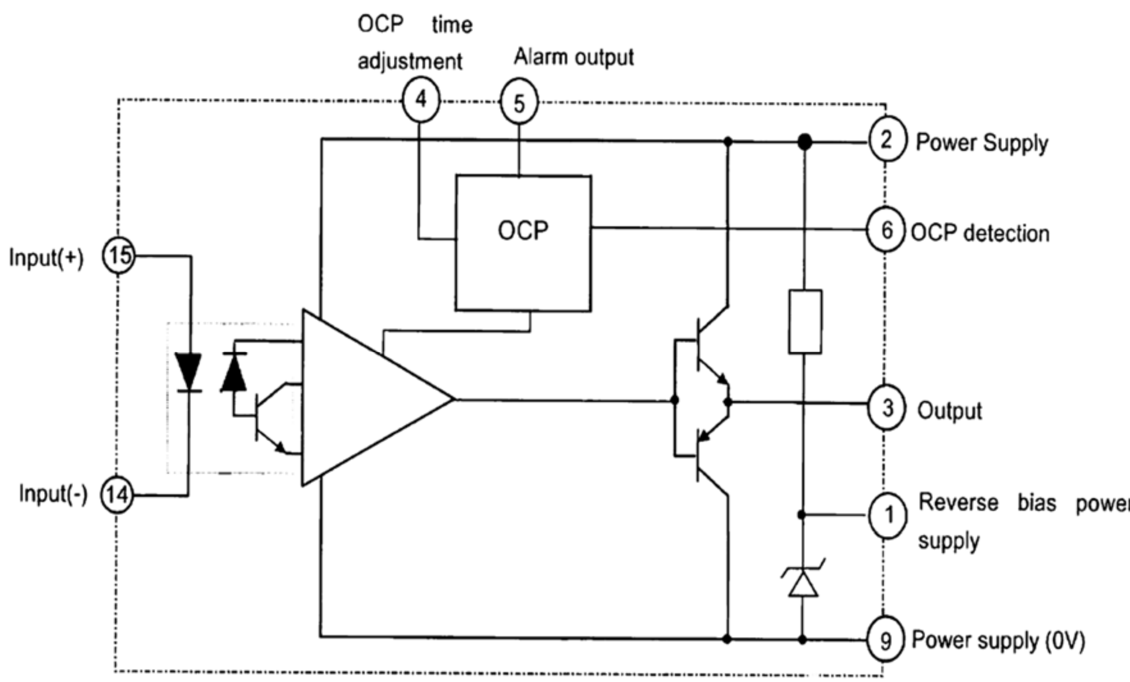


Fig.C1 Pin description of IC

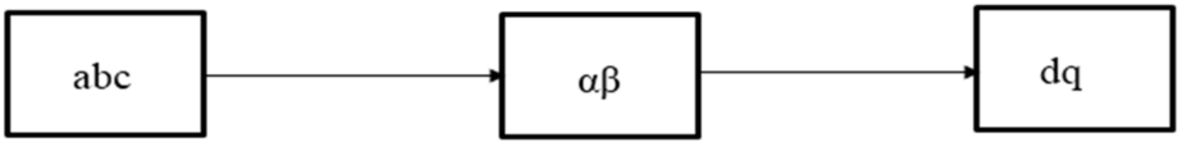
(Unless otherwise noted, Ta=25°C, V_{CC} = 20V, I_{in}= 10mA)

Symbol	Parameter	Conditions	Limits			Unit
			Min	Typ	Max	
Vcc	Power supply voltage	Recommended range	20	-	22	V
Iin	Photo coupler input current	Recommended range	9	10	11	mA
f	Switching frequency	Recommended range	-	-	40	kHz
RG	Gate resistance	Recommended range	1.1	-	-	Ω
VOH	"H" output voltage	-	-	14.5	-	V
VOL	"L" output voltage	-	-	-4	-	V
ton	Switching time 1	-	-	-	1.5	μs
tr	Rise time	-	-	-	1.0	μs
toff	Switching time 2	-	-	-	1.5	μs
tf	Fall time	-	-	-	1.0	μs
Vocp	OCP operating voltage	-	-	8.5	-	V
tocp	OCP delay time	-	-	-	10	μs
tALM	Alarm delay time	-	-	-	1.5	μs
VRB	Reverse bias power supply voltage	-	-	5	-	V

Fig.C2 Electrical characteristics of Gate Driver IC

Appendix D

1) abc to d-q transformation via α-β transformation

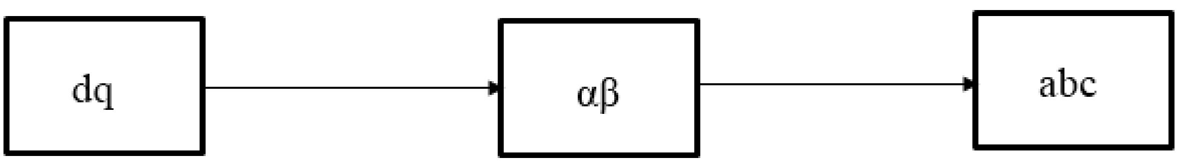


$$\begin{bmatrix} f_\alpha \\ f_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix}$$

$$\begin{bmatrix} f_d \\ f_q \end{bmatrix} = \begin{bmatrix} \cos\emptyset & \sin\emptyset \\ -\sin\emptyset & \cos\emptyset \end{bmatrix} \begin{bmatrix} f_\alpha \\ f_\beta \end{bmatrix}$$

$$\begin{bmatrix} f_d \\ f_q \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\emptyset & \cos(\emptyset - \gamma) & \cos(\emptyset + \gamma) \\ -\sin\emptyset & -\sin(\emptyset - \gamma) & -\sin(\emptyset - \gamma) \end{bmatrix} \begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix}$$

2) d-q to abc transformation via α-β transformation



$$\begin{bmatrix} f_\alpha \\ f_\beta \end{bmatrix} = \begin{bmatrix} \cos\emptyset & -\sin\emptyset \\ \sin\emptyset & \cos\emptyset \end{bmatrix} \begin{bmatrix} f_d \\ f_q \end{bmatrix}$$

$$\begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} f_\alpha \\ f_\beta \end{bmatrix}$$

$$\begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\emptyset & -\sin\emptyset \\ \cos(\theta - \gamma) & -\sin(\theta - \gamma) \\ \cos(\theta + \gamma) & -\sin(\theta + \gamma) \end{bmatrix} \begin{bmatrix} f_d \\ f_q \end{bmatrix}$$

$$\gamma = \frac{2\pi}{3}$$

$\emptyset$ = Angle between d-q and αβ reference frames